Reducing Development Time for Advanced Medical Endoscopy Systems with an FPGA-Based Approach

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The market trends for medical endoscopy systems present a variety of challenges, such as the need for increased functionality, higher definition, improved processing performance, and smaller profiles. This white paper describes Altera's solution using the 1080p Video Design Framework, DSP building blocks, reference designs, and Stratix® V, Cyclone® V, and Arria® V FPGAs.

Introduction

The demand for endoscopic procedures is increasing, and improvements in the screening process and medical equipment need to keep pace. New required features, variations for new markets, and shorter development schedules due to increasing worldwide competition require engineering teams to focus on their core competencies and system knowledge. Engineers require a flexible hardware platform and framework tools that support a variety of platforms, allowing them to upgrade their products due to new or changing standards. Additionally, design teams must make their development frameworks more efficient. The Altera® 1080p Video Design Framework and 28-nm FPGAs provide a flexible and systematic approach to handle current and evolving feature requirements.

Increasing Global Demand

Many factors have caused an increased demand for endoscopic procedures. As the world population over the age of sixty significantly increases over the next several decades, the need for healthcare services will also increase. Additionally, there is an increasing prevalence of gastrointestinal diseases among populations that require screening and treatment. More physicians are adopting endoscopic screening procedures. Many government reimbursement policies favor noninvasive procedures, which have faster patient recovery time, resulting in lower overall treatment costs and more positive patient experiences.

Many countries are also investing in their healthcare infrastructure, with particularly high growth in medical equipment purchases. In turn, needs from these new markets are expanding the requirements placed on next-generation endoscopic systems. Design teams experience ever-increasing requirements while global competition shrinks their product release schedules.

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Equipment Trends

Endoscopic systems require increasing functionality. Many available endoscopic platforms are considered high-definition (HD) systems. However, surgeons continue to request even higher definition platforms as technology innovations progress. The resolution is strongly dependent on the image sensor; however, the processing engine and interpolation schemes are important in determining the effective resolution. Future platforms will need higher resolutions such as 4K x 2K.

Multiple stream manipulation is another area where platforms differ. Systems will need features such as picture-in-picture, side-by-side viewing for multiple camera feeds or archive recall, and multiple image viewing (four or more simultaneous images). A user-friendly GUI should support switching from one mode to another. In surgical rooms, endoscopic systems will include multiple surgical-grade monitors positioned for viewing by the surgeons and staff. In these environments, archived images or radiographic images may be displayed side by side with the endoscopic video feed. Video transport to the video router and monitors must support various interface standards such as SDI and HDMI, as well as newer standards such as DisplayPort, CameraLink, and GigE Vision. Equipment platforms will support multiple standards, both legacy and future, as well as revision upgrades or more advanced algorithms.

Other enhancements are increased light intensity, depth of focus, optical zoom capabilities, and better definition digital zoom. To allow more efficient equipment and surgical room usage, the equipment should have a shorter set-up time (i.e., faster white balancing). Additional innovation areas include solutions for lens fogging.

Finally, as with other medical equipment, smaller profiles are desirable. Higher integration may allow for smaller, portable, cart-based systems, while smaller tower systems allow easier cleanup after procedures.

Technical Requirements

Many endoscopic system equipment trends relate to increased processing performance, which in turn supports more advanced imaging algorithms. As image sensor technology improves, higher resolution streams can be captured for pre- and post-processing. Systems will need to process more image data from the camera head and implement increasingly complicated processing functions in the processing engine.

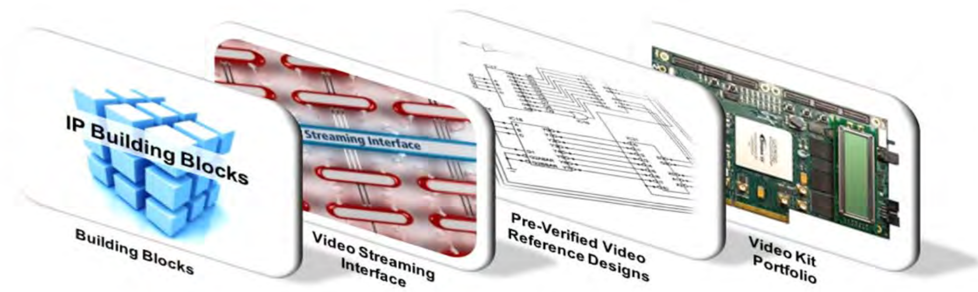
Designers need to implement these functions in high-performance processing devices, such as FPGAs, that allow for scalable performance across platform generations. FPGAs tend to lead the process curve for technology nodes because each generation of devices can integrate more processing resources (such as logic elements (LEs), digital signal processing (DSP) resources with floating-point support, on-die memory, and faster I/O support). Additionally, the intrinsic FPGA structure lends itself to parallel processing, which is advantageous for imaging algorithms.

Flexible, re-programmable FPGAs are good companion devices to image sensor integrated circuits because the devices can handle inherent nonlinearities. Additionally, FPGAs have high-performance I/O capabilities that allow support for interface standards such as SDI, DVI, SAS/SATA, and USB.

Medical Video Development Environment

Altera offers a complete design environment that allows engineers to develop medical endoscopy imaging application quickly and to increase design productivity. As shown in Figure 1, it includes the 1080p Video Design Framework that integrates Altera, Altera partner, or custom video-processing intellectual property (IP) blocks with streaming interfaces and connects with the desired external interface for video display, transport, or storage. Within this framework, Altera provides a video development kit that contains various reference designs. Altera also offers the DSP Builder software, which is a high-level design tool that integrates with The MathWorks MATLAB and Simulink software. Designers can use this software to model various algorithms and integrate the 1080p Video Design Framework.

Figure 1. Altera's Medical Video Development Environment

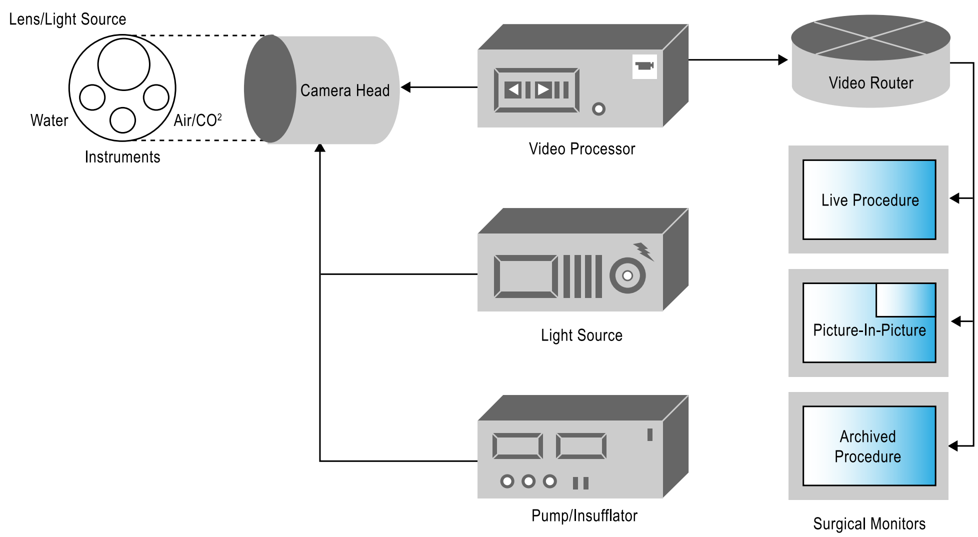


This design methodology lets the medical equipment designer focus on value-added functions, and provides a faster path from concept to production. It also enables a more scalable system for porting designs to different Altera devices and differentiates product offerings from lower cost models to high-performance product lines.

Endoscopic System

Figure 2 shows the physical equipment: an endoscopic tower consisting of several system components. Hand controls allow the surgeon to manipulate the endoscope (rigid or flexible), which contains the lens, light path, tools, and water/gas outlets. The endoscope head is connected through fiber optics to the light source, which generates a controlled high-intensity illumination that can be manipulated by the surgeon during the procedure. The endoscope also connects with the camera head, which contains the image sensor (either single or three-chip arrays) and video-preprocessing electronics. The camera head generally requires a smaller footprint because it is hand held. The camera head is connected to the video processing box, which performs the processing functions that generate high-quality video. It also performs the display and video transport functions to deliver the procedure's video to the local display or through a video router to the medical-grade monitors positioned in the operating room. The endoscopic tower can also contain a video recorder or storage device so that procedures can be reviewed at a later date. Finally, the endoscopic tower contains the insufflators that inject CO_2 into body cavities to maintain a pressure level in the body. This pressure allows the medical professional to view or manipulate organs and tissue within the body.

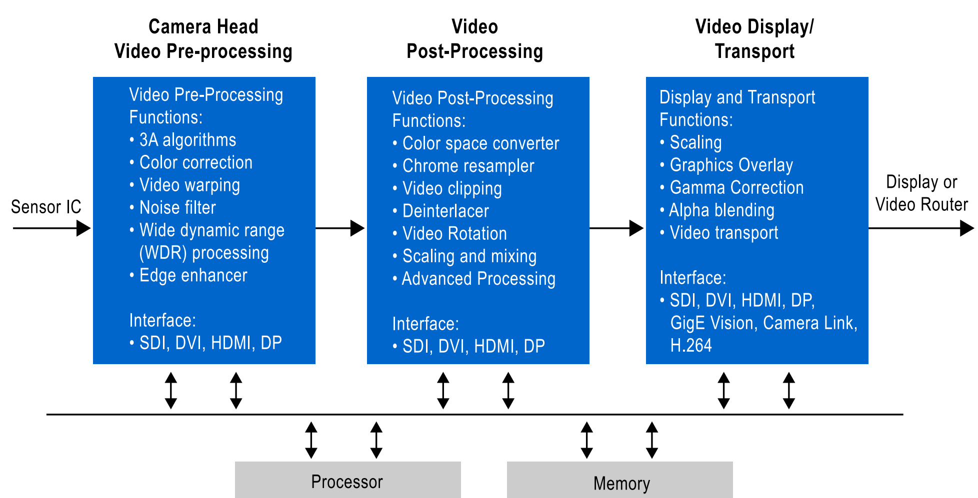
Figure 2. Endoscope Tower (System) Diagram



The image data path and corresponding processing functions can be logically grouped into three sections (see Figure 3):

- Video preprocessing
- Video post-processing
- Video display/transport

Figure 3. Endoscope System Functional Diagram



Camera Head Video Preprocessing

In the video-acquisition stage of raw video image and preprocessing, different image processing algorithms contribute to a superior endoscopy camera video. Imaging architects use high-level software tools to model various algorithms and results. Designers can use open-source toolkits for image registration and segmentation. These tools are optimized for imaging applications and algorithm development via software, but not for implementation into FPGAs. Altera's fixed-point and floating-point design methodology, algorithmic development in the MATLAB software, and system-level design in the Simulink software provide designers with an efficient DSP design approach for high-performance FPGA implementation. Altera also partners with experienced design houses in the industry for camera processing pipeline algorithm solutions and preprocessing. Altera Cyclone V and Arria V FPGAs meet the design requirements for this video processing stage:

- Cyclone V devices offer the industry's lowest system cost, and power and performance levels that make the device family ideal for differentiating high-volume applications.
- Arria V FPGAs balance cost and performance while delivering the lowest total power for mid-range applications.

Video Post-Processing

Video processing is a natural fit for FPGAs, particularly with the transition to 1080p HD or 4K resolutions. Using Altera's existing video post-processing solution allows designers to focus more on the value-added functions that matter to specific target markets. The 1080p framework can incorporate Altera's Video and Image Processing (VIP) suite of IP cores with a user-defined algorithm developed in HDL or Simulink. The Qsys system integration tool makes it easy to integrate the design with a standard streaming protocol.

Video Display, Transport, and Storage

Altera's 1080p Video Design Framework supports a variety of video and storage interfaces, including SDI, DVI, HDMI, DisplayPort, CameraLink, SAS/SATA, USB, custom, and proprietary standards. As part of this framework, Altera offers a complete up, down, and cross conversion (UDX) reference design with a dual-channel video-processing pipeline to jump-start a design. 4K resolution, with its picture clarity and realism, is a desired video enhancement. The 4K video upscaling format conversion reference design upscales to 4K resolutions by receiving a 1080p video format over a 3G-SDI interface, upscaling it to 4K x 2K resolution, and sending the output over four 3G-SDI interfaces.

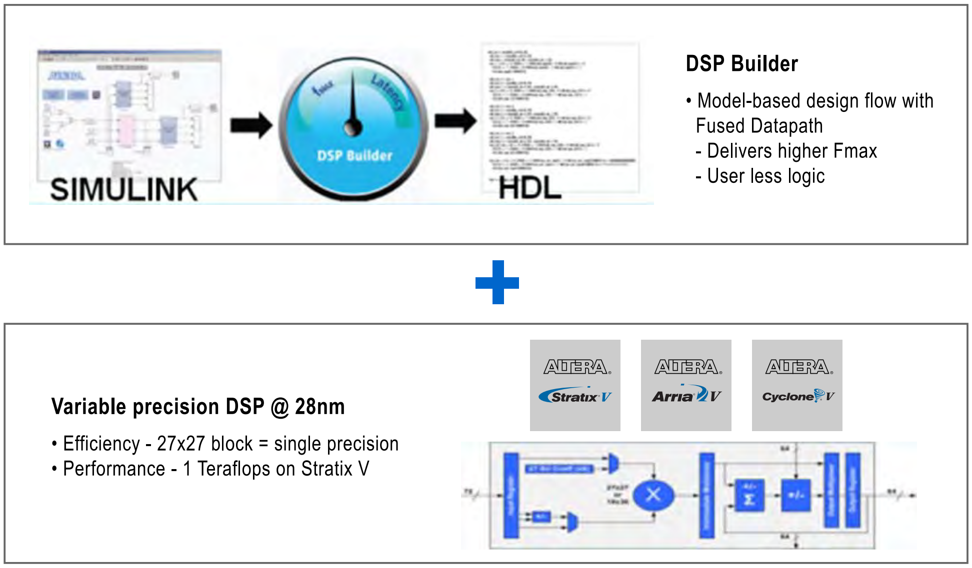
Altera Solution for Endoscopy System

Altera's variable precision DSP, 1080p Video Design Framework, and 4k reference design can increase design productivity and help address medical endoscopy equipment design requirements.

Variable Precision DSP at 28 nm

In any advanced medical imaging solution, high-performance DSP resources and efficient design tools are needed to meet the system requirements. As shown in Figure 4, Altera's DSP Builder tool plus variable-precision DSP delivers an efficient floating-point or fixed-point DSP design for specific video algorithms.

Figure 4. Custom Fixed-Point or Floating-Point Algorithm DSP Solution



The DSP Builder Advanced blockset allows designers to perform high-level Simulink synthesis as well as timing-driven optimizations in a MATLAB/Simulink design. Design optimization for meeting the user-specified $\mathbf{f_{MAX}}$ or latency—from within a high-level tool such as Simulink—is a feature that is unique to Altera and some vendor tools. Fundamentally, this means that the designer can set a "dial" to the $\mathbf{f_{MAX}}$ and latency that the system requires, and the DSP Builder tool takes care of the rest. The tool can add in registers to increase $\mathbf{f_{MAX}}$ or parallelize certain critical paths to meet latency constraints, eliminating weeks of hand-tweaking the resultant HDL code.

Altera's 28-nm FPGAs have native support for single-precision multipliers, making them well suited for fixed-point and floating-point implementations. Altera's Stratix V FPGAs, with their unique variable-precision DSP architecture, can deliver performance up to one trillion floating-point operations per second (teraFLOPS).

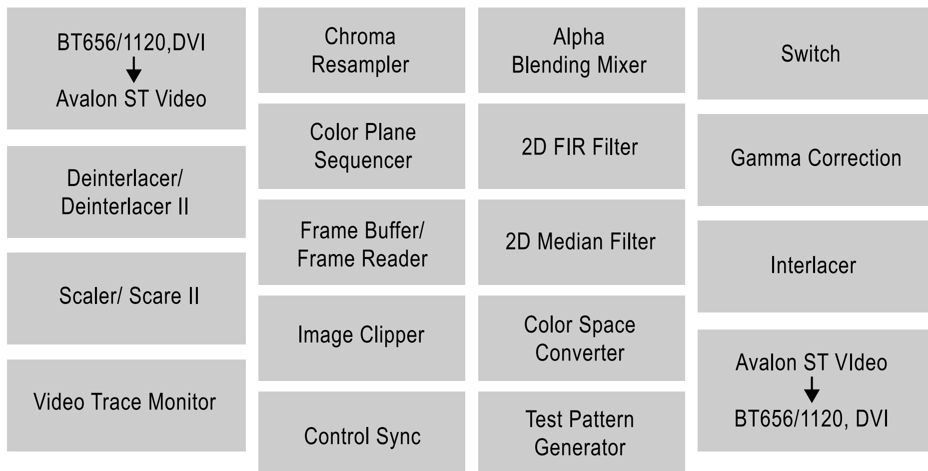
1080p Video Design Framework

Increasing the productivity of the medical design team requires access to framework tools that are high-performance and easy to use, as well as support a variety of functions and IP. While other FPGA vendors have a few disparate video functions, Altera is the only vendor that provides a design framework with 20 video functions, a streaming video interface standard, over half a dozen hardware-verified reference designs, and a range of video development kits. With Altera's 1080p Video Design Framework, designers can start with existing working designs, reuse pre-verified IP for common functions such as scaling, deinterlacing, and mixing, add in custom functions or the OEM's internal IP, and complete the design in a fraction of the time it would take to develop a new design from scratch.

VIP Suite

A key component of the 1080p Video Design Framework is the VIP Suite of IP Cores, shown in Figure 5, which is used for a variety of imaging datapaths. The VIP Suite includes 20 commonly used building-block functions that range from a simple color space converter or alpha blending mixer to highly sophisticated functions for polyphase scaling and motion-adaptive deinterlacing. Additionally, Altera partners provide imaging IP—for noise reduction, edge detection, local area processing, and stabilization and rotation—to aid development.

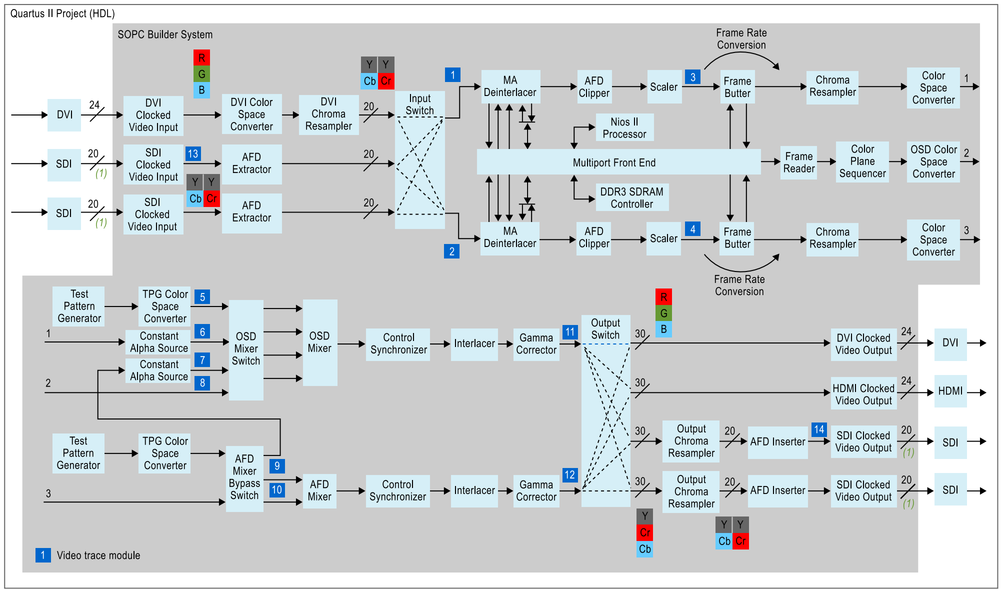
Figure 5. VIP Suite of IP Cores



Broadcast Quality Reference Design

A new endoscopic system may be installed with existing equipment or with older generation video routing equipment and medical grade-monitors from a variety of other vendors. This setup requires the newer endoscopic system to support new and legacy video standards. Altera's HD video reference designs, such as that shown in Figure 6, deliver high-quality UDX designs for standard-definition (SD), HD, and 3-Gbps video streams in interlaced or progressive format. These reference designs are highly software and hardware configurable, enabling rapid system configuration and design. The designs target typical broadcast applications and can be used in a medical video application as a high resolution display, video switcher, multi-viewer, converter, and distance surgical-conferencing applications. These reference designs are available with the high-performance Stratix IV GX and lower cost Arria V GX development kits.

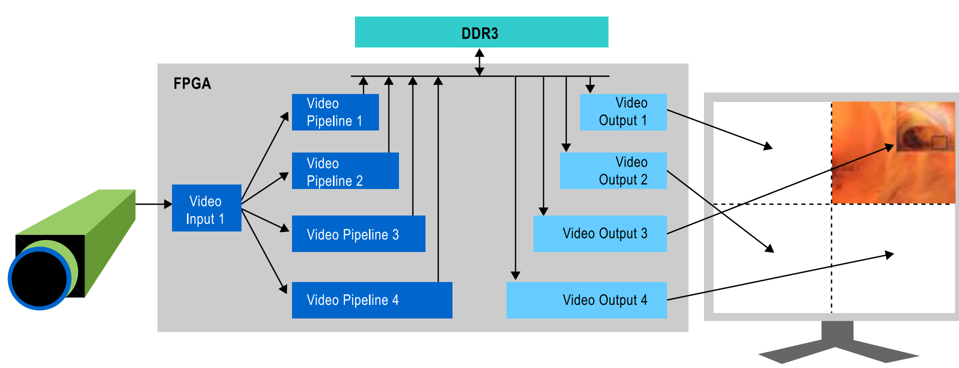
Figure 6. Broadcast-Quality Reference Design Block Diagram



4K Video Upscaling Format Conversion Reference Design

Endoscopic surgeons often cite increased image resolution as a primary consideration when selecting equipment. 4K resolution is rapidly becoming the next major video enhancement because of its picture clarity and realism. Altera enables this next generation of applications by reducing the system chip count, which lowers the overall bill of materials (BOM) cost, as well as reducing the cost of development and simplifying board design. Previous systems required as many as nine off-the-shelf chips to perform 4K format conversion (four 1080p format conversion chips and five chips for SDI input and output). Altera's 4K video upscaling format conversion reference design (see Figure 7) uses 20% of the resources in a single Stratix V FPGA (5SGXEA7). The design can be integrated easily with ample headroom remaining to incorporate picture-in-picture function from an existing or additional video source, other video functionality, and interfaces such as DisplayPort, HDMI, and video compression (encoding/decoding) processing. Using Stratix V devices also provides a migration path to any of Altera's new FPGA device families, allowing designers to take advantage of new device features and functionality.

Figure 7. 4K Video Upscaling Format Conversion Reference Design Block Diagram



Conclusion

The changing global landscape for the endoscopic systems market requires more product variations with less time to develop new platforms. Engineering teams will need to take advantage of time-saving, efficient design methodology. Altera's 1080p Video Design Framework provides a flexible and systematic approach to handle current and evolving features. Altera's 28-nm FPGAs improve floating-point DSP capability, delivering high performance and efficient implementation of advanced imaging functions. With these solutions, medical equipment design teams can focus their efforts on developing value-added expertise and accelerate their time to market with product variations.

Further Information

- Altera Floating-Point DSP Solutions:
  www.altera.com/technology/dsp/floating-point/dsp-floating-point.html
- Diagnostic Imaging Solutions:
  www.altera.com/end-markets/medical/diagnostic/med-diagnostic.html
- Life Science and Hospital Equipment:
  www.altera.com/end-markets/medical/science/med-science.html
- 1080p Video Design Framework:
  www.altera.com/technology/dsp/applications/1080p-hd-video/dsp-1080p-hd-video.html
- Video and Image Processing (VIP) Suite:
  www.altera.com/products/ip/dsp/image_video_processing/m-alt-vipsuite.html
- Video Reference Designs:
  www.altera.com/technology/dsp/ref_design/dsp-video.html
- 4K Video Upscaling Format Conversion Reference Design:
  www.altera.com/support/refdesigns/sys-sol/broadcast/ref-4k-video-upscaling.html
- Altera DSP Designer Training:
  www.altera.com/education/training/curriculum/dsp/trn-dsp.html

Acknowledgements

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Document Revision History

Table 1 shows the revision history for this document.

Table 1. Document Revision History

Date	Version	Changes
August 2012	1.0	Initial release.